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TERRAIN-INFLUENCED TORNADOGENESIS IN THE NORTHEASTERN UNITED STATES

by

Lance F. Bosart[1], Kenneth LaPenta[3], Anton Seimon[2], Michael Dickinson[4], and Thomas J. Galarneau, Jr.[1]

[1]Department of Earth and Atmospheric Sciences
The University at Albany/SUNY
1400 Washington Avenue
Albany, NY 12222
Ph: 518-442-4564
Fax: 518-442-4494
Email: bosart@atmos.albany.edu

[2]Earth Institute of Columbia University
Lamont-Doherty Earth Observatory, IRI-Monell Building
Palisades, NY 10964

[3]National Weather Service Forecast Office
Center for Environmental Sciences and Technology Management
The University at Albany/SUNY
251 Fuller Road
Albany, NY 12203

[4]Accurate Environmental Forecasting
Narragansett, RI 02882

1. INTRODUCTION:

On 29 May 1995, a supercell thunderstorm traveling a corridor across prominent topographic landforms in the northeastern United States (US) produced an almost continuous 50 km track tornado that caused damage of up to F3 intensity (Grazulus 1997). The damage swatch ranged up to 1 km in width, with severe forest destruction and structural damage reported. Maximum impact was felt in Great Barrington (GBR), Massachusetts, where widespread structural damage occurred and 3 people were killed when a vehicle was thrown more than 500 m by the tornado (Storm data, 1995). The purpose of this paper is to conduct a detailed examination of the evolution of the GBR storm and its interaction with the complex terrain.

In its size, intensity, longevity, and most significantly, its occurrence over complex terrain, the GBR tornado represents a rare event, though it is far from unique. On occasion, tornadic storms will form over relatively flat terrain but then propagate into hilly or mountainous regions with their tornadic circulations remaining intact. Examples include the long-track Adirondack tornado in New York State in 1845 (Ludlam 1970), the Shinnston, West Virginia tornado that killed 103 during an outbreak on 23 June 1944 (Brotzman 1944; Grazulis 1993), and several tornadoes of the 31 May 1985 outbreak that propagated from eastern Ohio into the hilly terrain of northwest Pennsylvania (Storm Data, 1985; Farrell and Carlson 1989).

The GBR tornado occurred over a topographic environment of comparable relief to reported Rocky Mountain tornado events (e.g., Evans and Johns 1996), although at lower overall elevations. Terrain in the Appalachian mountain system of the northeastern United States averages ~2 km lower than the Rockies; however, the magnitude of terrain variations is often comparable, especially where deeply incised river valleys are located. The hilly, forested environments that characterize most of the northeastern US interior probably determine to a large degree why, despite an abundance of intense warm season convection, relatively few tornadoes are known to occur compared to the Midwest and Great Lakes at comparable latitudes further to the west.

The GBR storm was fortuitous in being observed with Doppler radar (WSR-88D) during both supercell development and the subsequent tornadic phase over complex terrain, thus providing for the opportunity to study tornadogenesis in the context of a supercell's underlying topography. Our analysis reveals compelling evidence supporting a hypothesis that terrain influences play a deterministic role in significant mountain tornado occurrence. We find that tornadogenesis in the GBR storm was supported by, if not actually attributable to, orogenic modifications of boundary-layer storm inflow and outflow as the parent supercell traversed a series of prominent topographic landforms.

2. RESULTS:

The case study analysis of the GBR

**Corresponding author address:* Lance F. Bosart, University at Albany/SUNY, Department of Earth and Atmospheric Sciences, 1400 Washington Avenue, Albany, New York 12222 USA; email: bosart@atmos.albany.edu

tornado has shown that the GBR supercell possessed a midlevel mesocyclone while it was located to the west of the Catskill Mountains and well before tornadogenesis. Our analysis revealed that the aforementioned mesocyclone intensified as it moved off the eastern end of the Catskill escarpment and entered the Hudson Valley. Our analysis further revealed that mesocyclone intensification also coincided with the serendipitous arrival of an accelerated terrain-channeled cold surge, triggered by additional convection to the north of the GBR supercell, down the topographic trough that marked the Catskill Creek and into the Hudson Valley. The eastward-moving GBR supercell intercepted the southeastward-moving cold surge down the Catskill Creek as the leading edge of the surge encountered the terrain-channeled southerly flow up the Hudson Valley (Fig. 1). Subsequently, the mesocyclone weakened as it moved upslope over the Taconic Range and into western Massachusetts before it intensified again as it moved downslope into the Housatonic Valley where it was associated with the GBR tornado.

Radar observations showed that the GBR supercell possessed a mesocyclone well prior to tornadogenesis. Rotational velocities at the three lowest radar beam elevation angles (0.5°, 1.5°, and 2.4°) were ~10 m s^{-1} over 10 km as early as 1913Z/29 while the storm was still well west of the Catskills. These rotational velocity (shear) values correspond to an ambient relative vorticity of ~ 10^{-3} s^{-1} about a vertical axis. Over the next hour the radar-derived rotational velocity values increased steadily to ~15 m s^{-1} as the GBR supercell reached the western Catskills (Fig. 2). As the line of thunderstorms containing the GBR supercell became better organized a new thunderstorm developed behind the inferred cold outflow boundary 15-20 km to the northeast of the GBR supercell. This second storm also maintained its identity as it moved eastward across the northern Catskills. Although this second (northern) storm was secondary to the GBR supercell, it was important because an analysis of radar-derived base velocity fields showed that it was responsible for triggering a cold outflow boundary that surged eastward across Schoharie and southern Albany Counties in New York. When this outflow surge reached the headwaters of the Catskill Creek over the Heidelberg escarpment north of the high Catskills it accelerated and was channeled southeastward by the configuration of the Catskill Creek; this behavior might also involve the refraction of the outflow gust front around the barrier represented by the high Catskills.

An analysis of the KENX base velocity data showed that the outflow surge down the Catskill Creek reached the Hudson Valley at about the time the GBR supercell was encountering the outflow on its northern side. This occurred as the GBR supercell entered the Hudson Valley after traversing the steep escarpment marking the eastern edge of the Catskills. The significance of the serendipitous arrival of the Catskill Creek outflow surge into the Hudson Valley, where it could be intercepted by the eastward-moving GBR supercell, was that the distance between the inbound and outbound velocity maxima associated with the supercell mesocyclone decreased from 10-15 km to 5-6 km, resulting in a strengthening of the mesocyclone.

3. CONCLUSIONS:

Tornadogenesis in the Hudson Valley appeared to be related to a combination of terrain-channeled (below 1 km) southerly flow up the Hudson Valley and mesocyclone updraft-induced acceleration associated with the Catskill Creek cold surge. We conclude that that the behavior of the terrain-channeled flows down the topographic troughs marking the Catskill Creek and up the Hudson Valley, respectively, and the resultant tornadogenesis, is predicated by the chance propagation of the Great Barrington supercell across the complex, but highly defined, topographic domain of the Catskill Mountains-Hudson Valley region. Subsequent terrain-channeled flow interaction with the mesocyclone likely occurred in the Housatonic Valley prior to tornado reformation in Great Barrington, Massachusetts, where F3 damage and 3 fatalities were observed.

4. ACKNOWLEDGEMENT:

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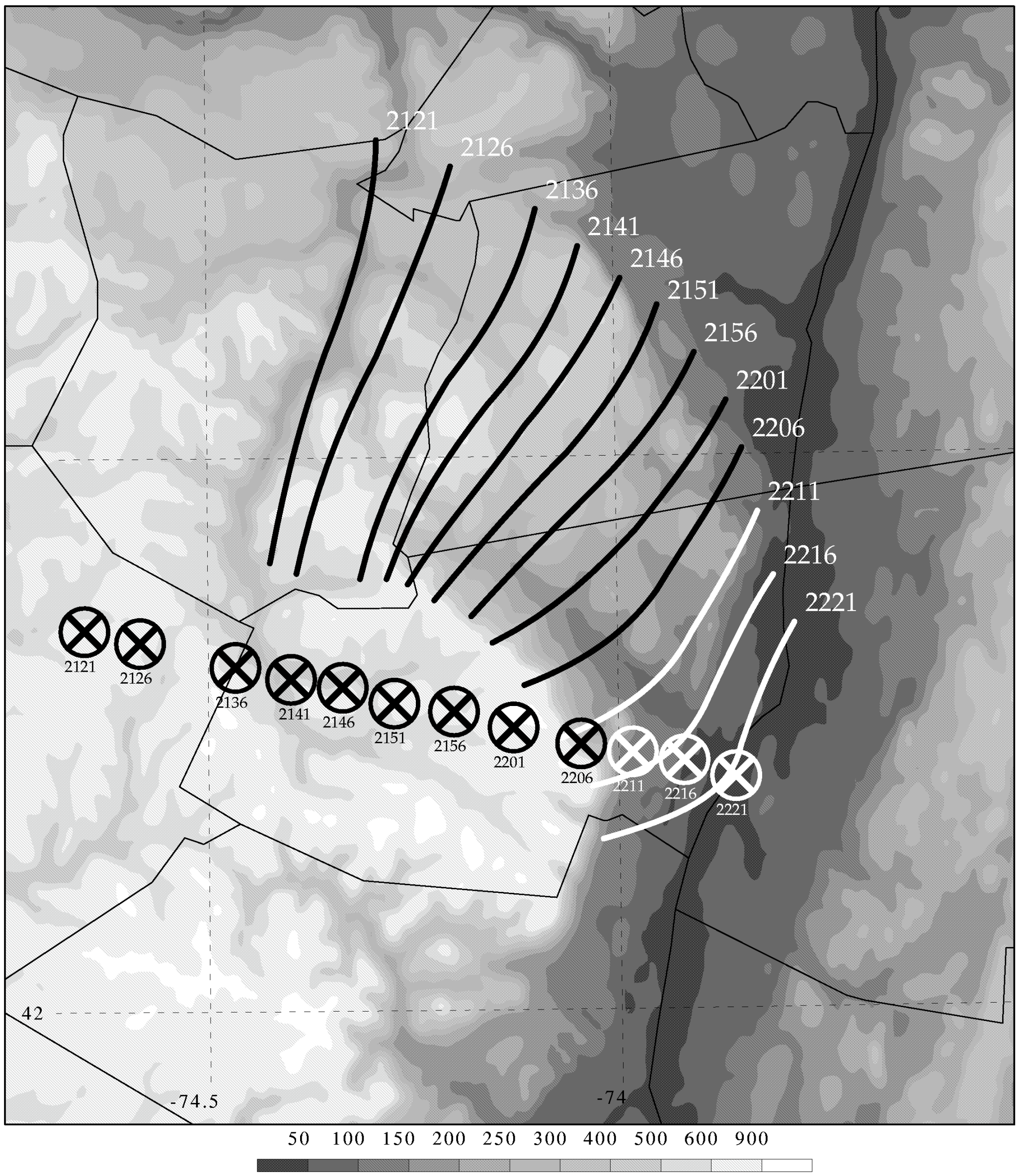

Figure 1: Isochrones of the leading edge of the Catskill Creek outflow boundary surge and position of the reflectivity core of the GBR storm on 29 May 1995 (marked by circle with 'x' at its center) for UTC times given. Note that the outflow boundary is far more extensive than the Catskill Creek Valley.

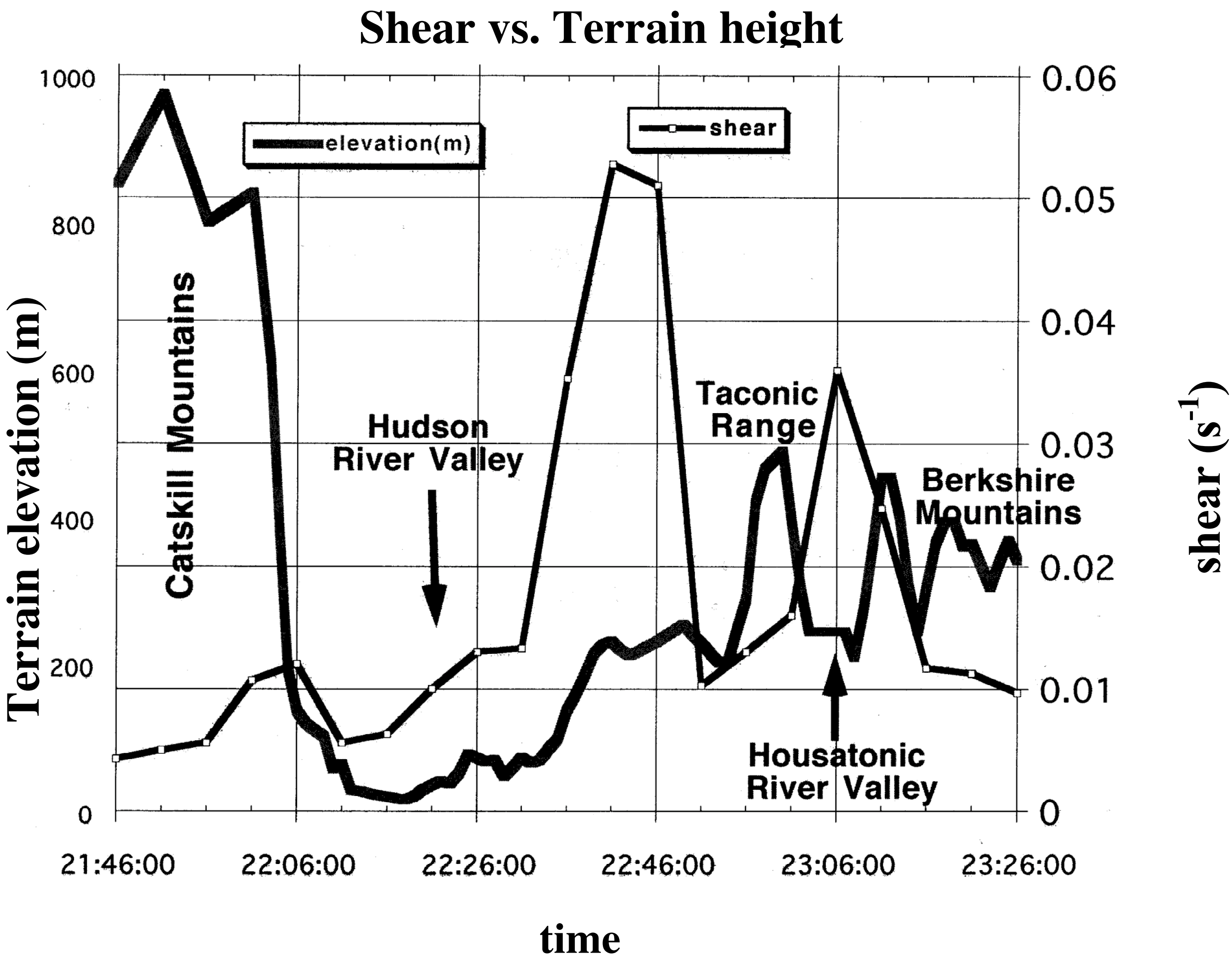

Figure 2: Inbound/outbound shear (s^{-1}; solid) derived from KENX WSR-88D volume scans averaged over the lowest three elevation scans (0.5, 1.5 and 2.4 degrees) along the disturbance path from 2146-2326 UTC 29 May 1995. Terrain elevation (m) given in solid (thick gray) with key topographic landforms labeled.